Fraunhofer

Institute of Applied Physics

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SET-171 Mid-IR Fiber Laser Workshop

Scaling of fiber laser systems based on novel components and high power capable packaging and joining technologies

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Outline

- **introduction**
- packaging and joining technologies
  - Application to microchip lasers
- novel components
  - Applications to fiber laser system scaling
- example of MID-IR source
- possible further directions

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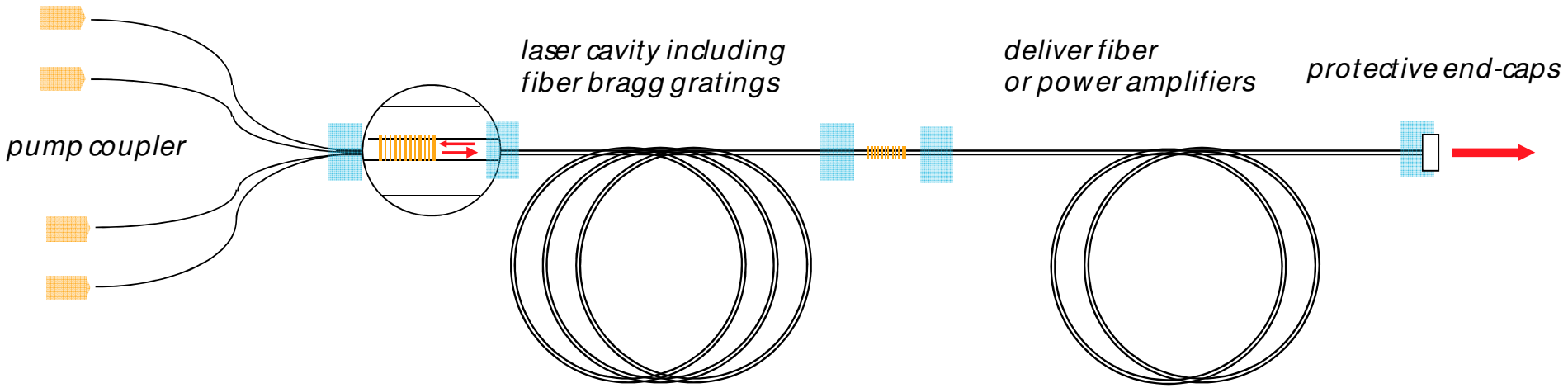
Fiber Laser
Introduction

- fiber lasers and amplifiers
  - high gain, excellent and power independent beam quality



  - all fiber setup for stability

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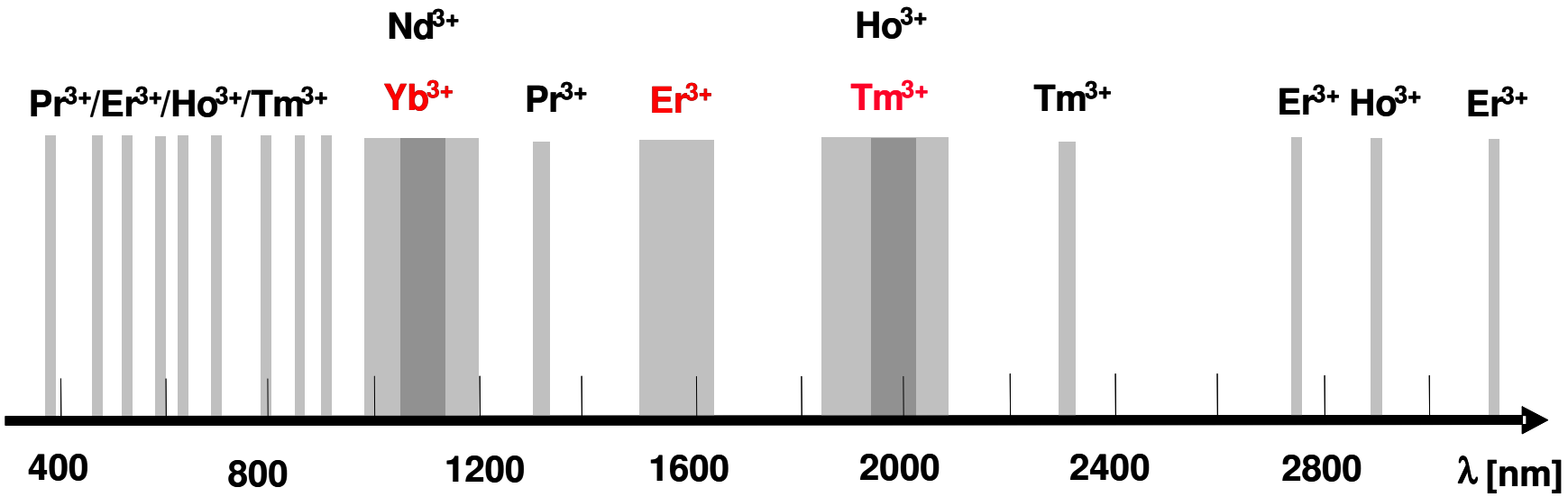
Fiber Laser
Introduction

- rare-earth doped fibers, kW average power levels available



- long wavelength by heavy metal cation fibers (e.g zirconium, ZBLAN fibers), which are not as „stable“ as fused silica)

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Fiber Laser
Introduction

- designing a (Mid-IR) source …

power and nonlinearity handling, optical properties …

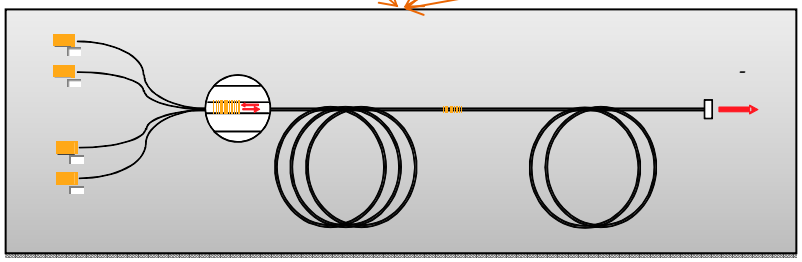
short pulsed, … , cw, broadband

Optomechanical requirements, Stability for military/space, …

components

architecture

packaging / joining



NLO

EUV

VIS

MID-IR

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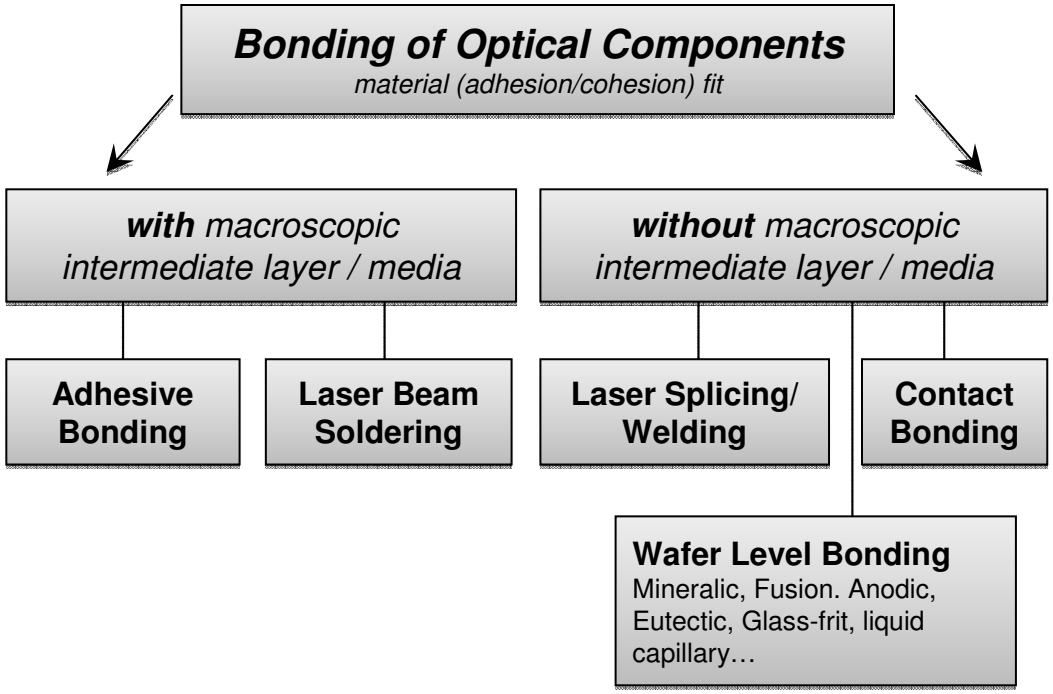
Overview of Joining Technologies for Optoelectronic Packaging

- Bonding of different materials always required
- material , thermal or optical contact desired



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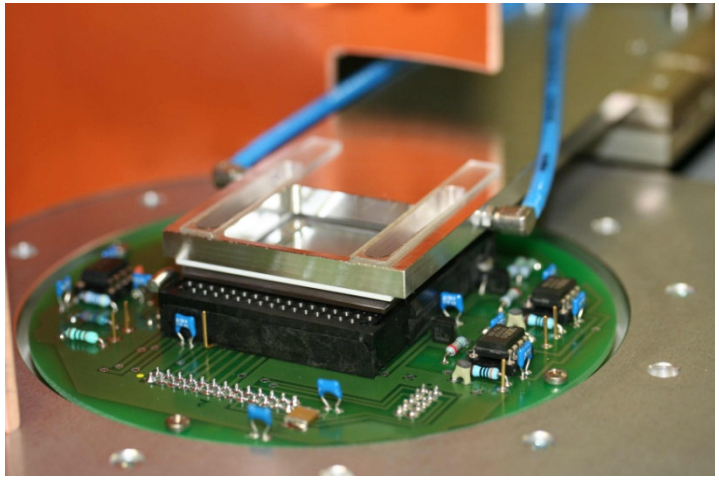
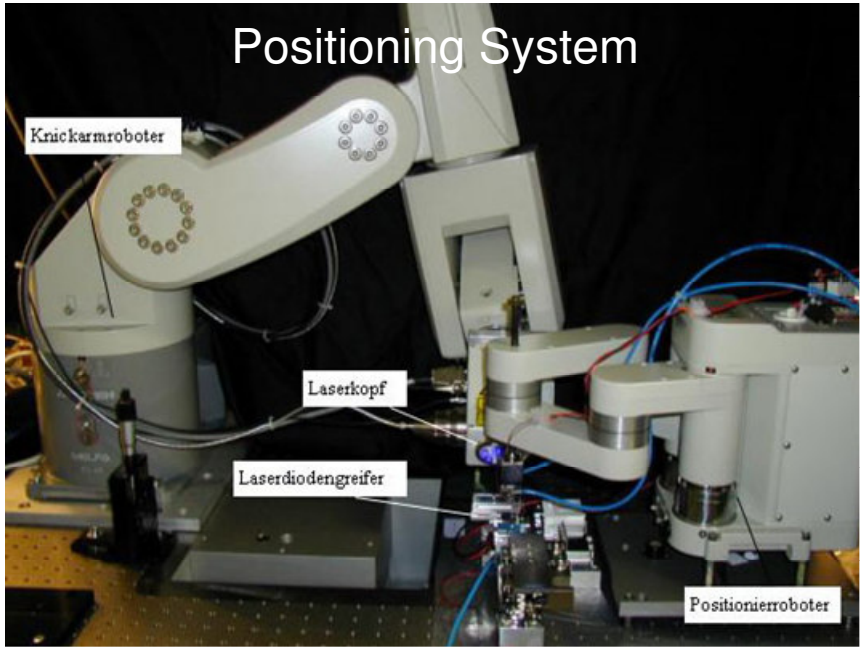
Bonding and Packaging of Optical Components
Adhesive Bonding

- Alignment of a Micro Lens Array to a CCD Sensor
  - 6 degrees of freedom
  - Alignment step wide: 0,1 – 1 µm





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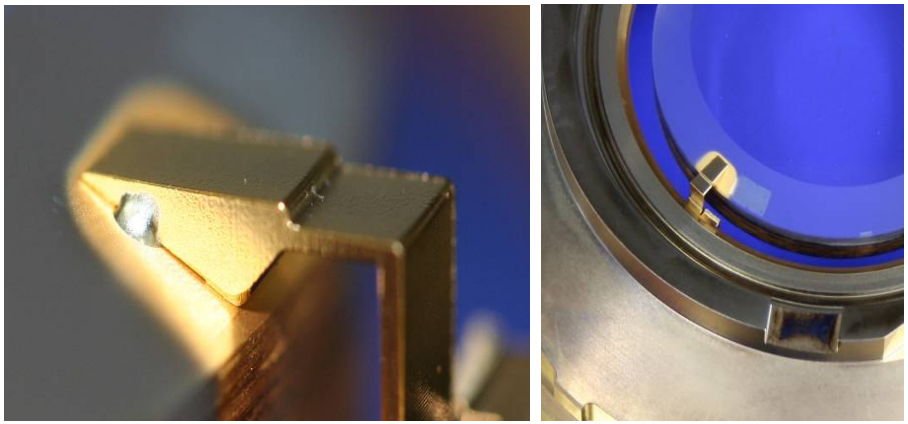
Bonding and Packaging of Optical Components

Laser Soldering

- long term stability
- high temperature stability
- high radiation stability compared to adhesives
- good vacuum compatibility / no outgasing
- high thermal and electrical conductivity
- flux free processing due to sputtered thin film metallization
- flexible and automated assembly



laser beam soldered optics for lithography

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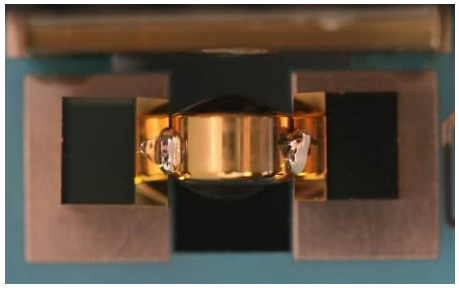
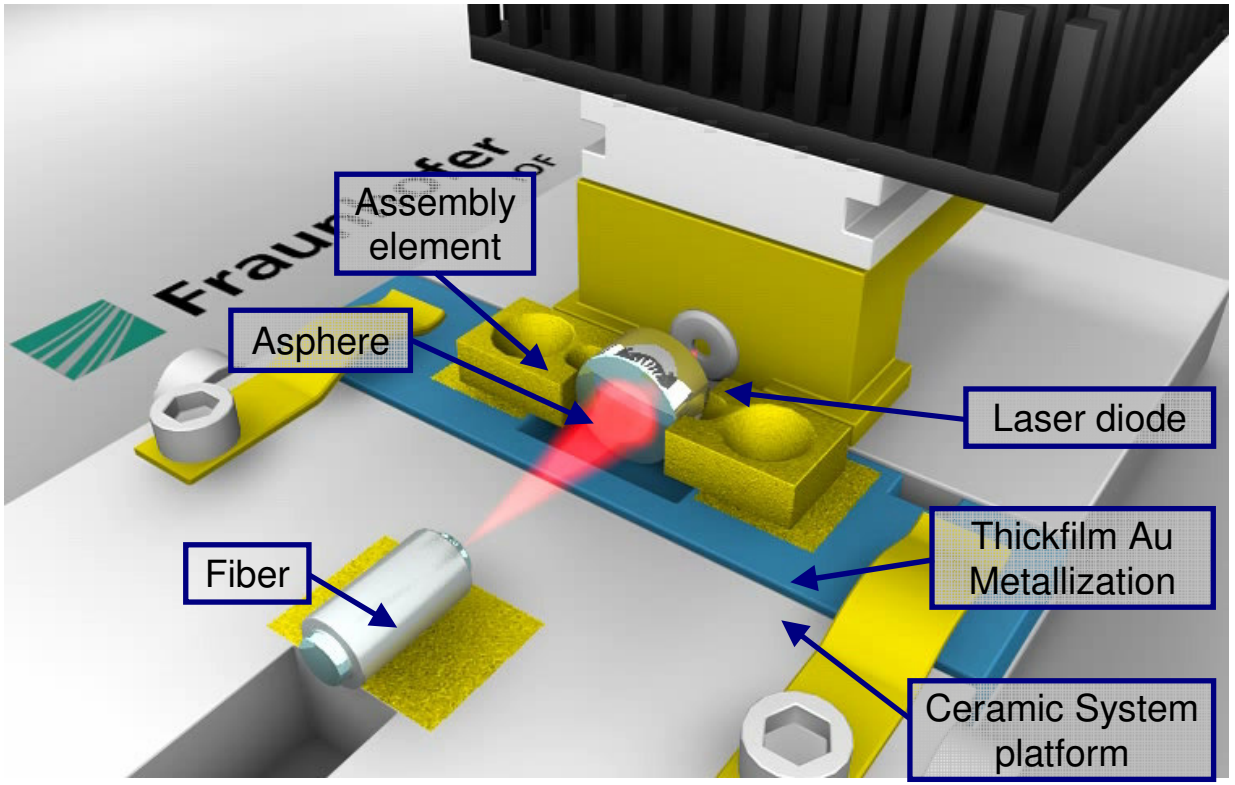
Bonding and Packaging of Optical Components
Solder Bumping

- Example of fiber coupled diode





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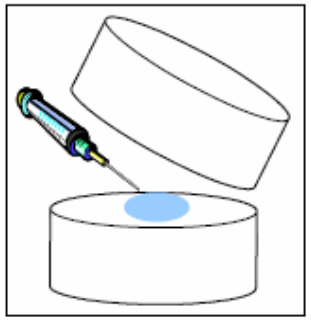
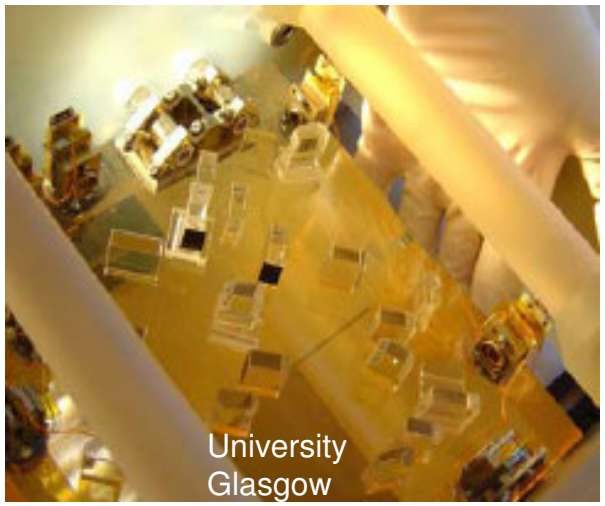
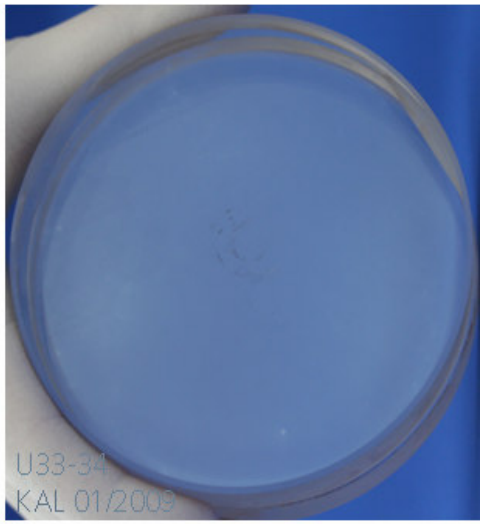
Bonding and Packaging of Optical Components

Mineralic Bonding

- inorganic bonding at low temperatures (≤ 200 °C) using special silicate solutions
- e.g. for high precision optical & mechanical systems
- high stability (intermediate layer <200nm)
  - low stress
  - “cold” bonding
  - NO creep
  - NO „out-gassing“







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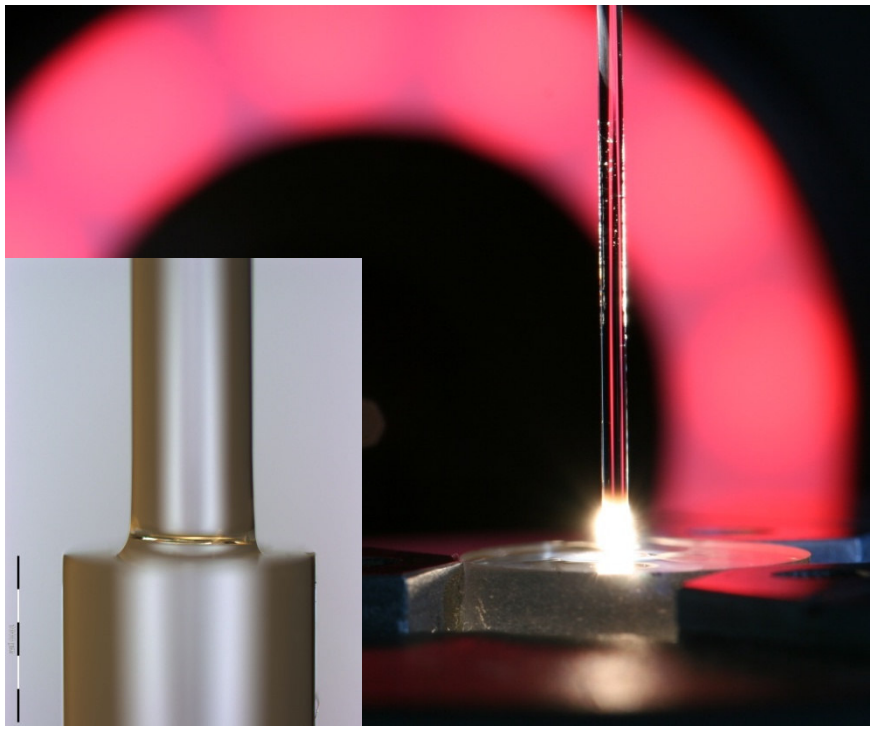
Bonding and Packaging of Optical Components

Laser based splicing and tapering

- Tapering and splicing device as well as process control developed
- easy adaptable
- very precise joints
- computer controlled process with high joining reproducibility
- mechanical stable welded joints
- high purity process without contaminations
- very low optical losses
- no consumables like process gas or filaments



Multimode fiber (ø720µm) with spliced end cap (ø1500µm)

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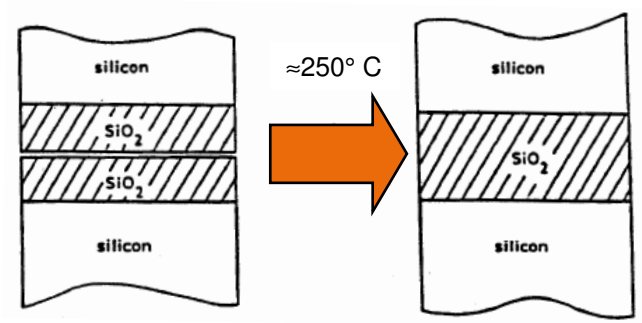
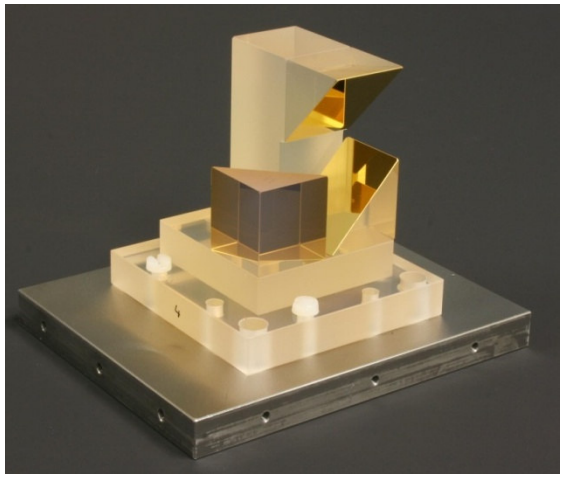
Bonding and Packaging of Optical Components
Direct bonding

- Without additional material – surface activation
- direct bond by a Waals forces
- very small tolerances



- jonts are sensitive to shock
- adjustment only within the plane of joining



- assemblies tested under vacuum and cryogenic environment

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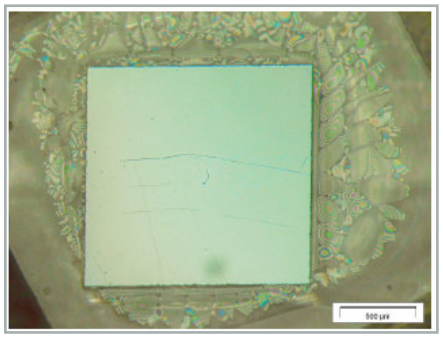
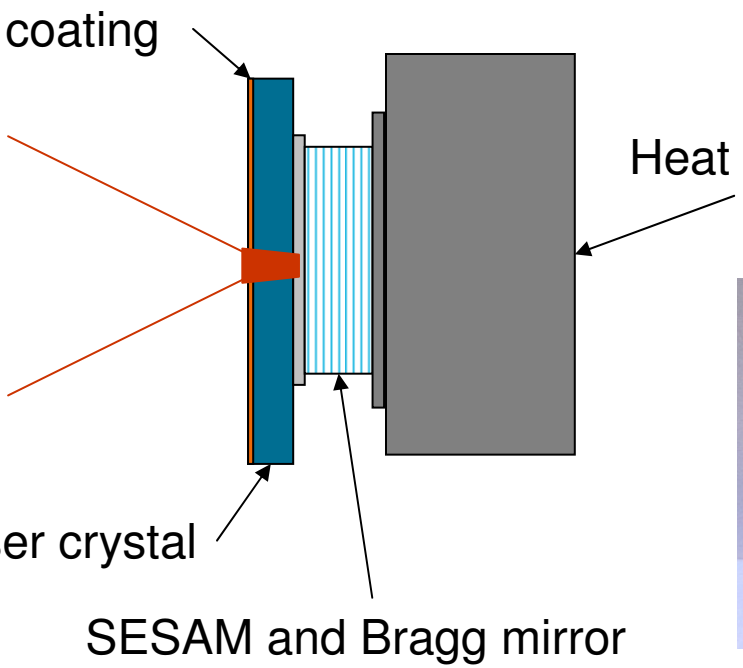
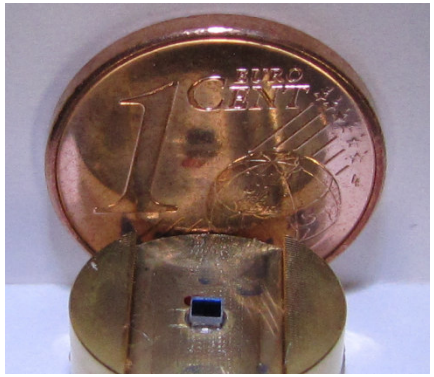
Scaling of fiber laser systems
Novel components and laser systems

- Microchip laser system using bonding technology







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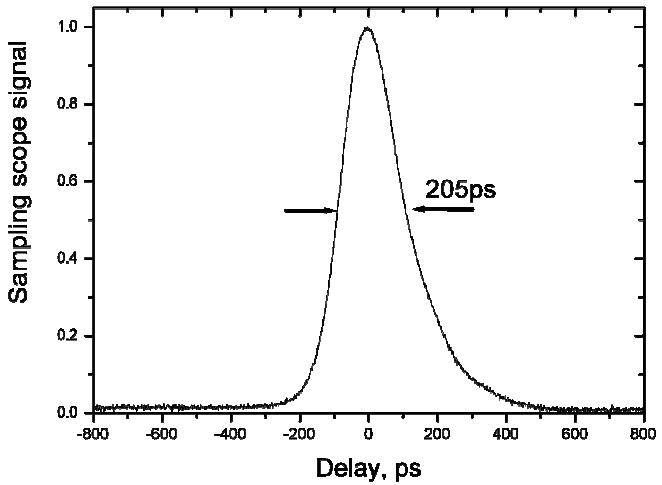
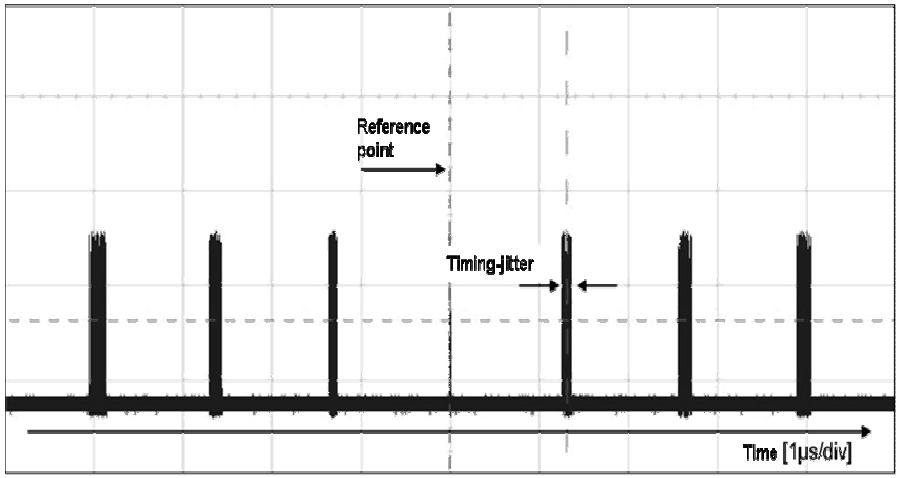
Scaling of fiber laser systems
Novel components and laser systems

- Microchip laser system using bonding technology
  - Unwanted jitter (typical for Q-switched lasers)





200 ps, Slope efficiency of ~ 35%, Ep = 120 -140 nJ, Repetition rate up to 2 MHz

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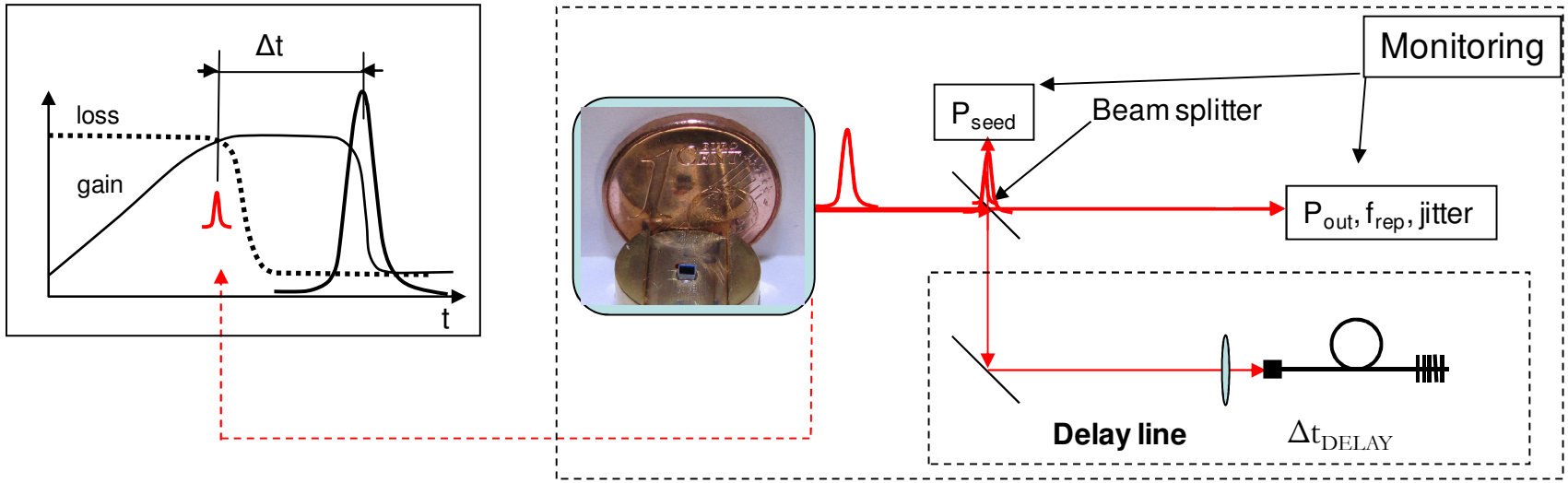
  - Unwanted jitter (typical for Q-switched lasers)
  - Self-injection seeding



A.Steinmetz et al. Applied Physics B (2009) 97: 317–320

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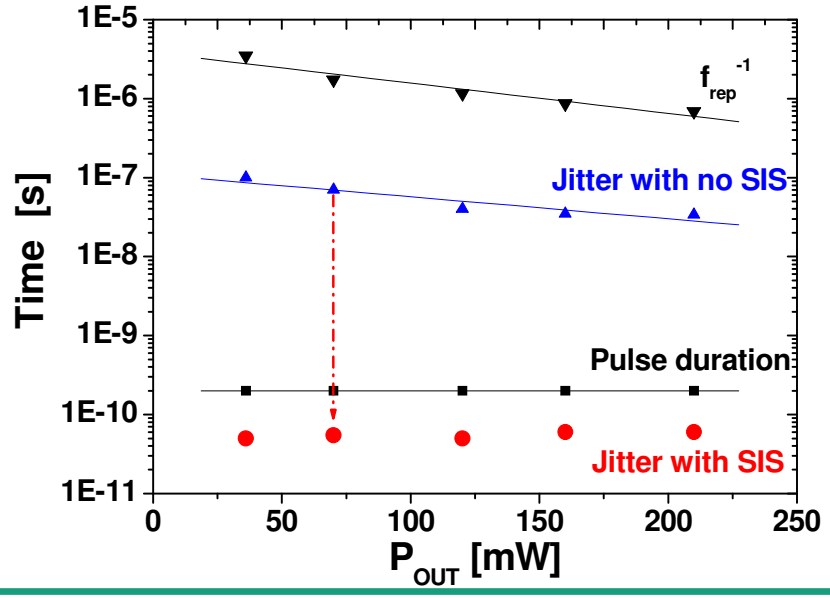
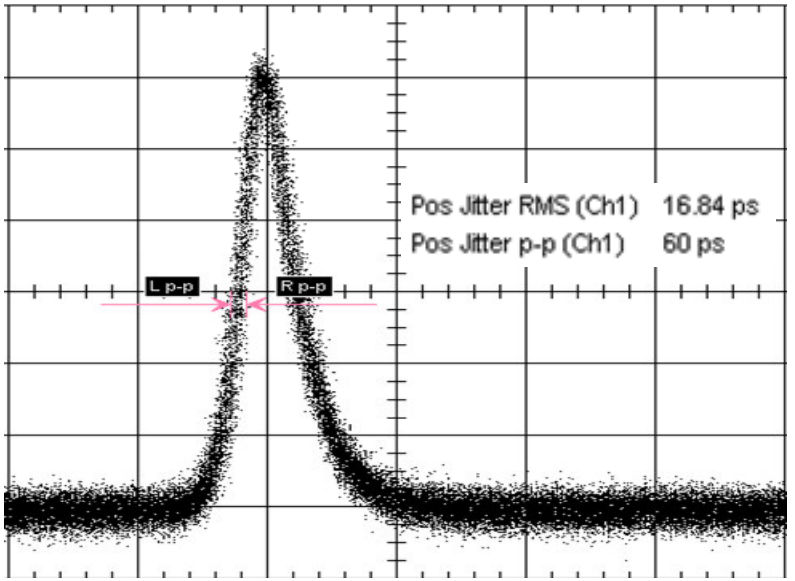
Scaling of fiber laser systems
Novel components and laser systems

- Microchip laser system using bonding technology
  - Unwanted jitter (typical for Q-switched lasers)
  - Self-injection seeding
  - Low cost alternative to mode-locked lasers





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- **novel components**
  - Applications to fiber laser system scaling
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- possible further directions

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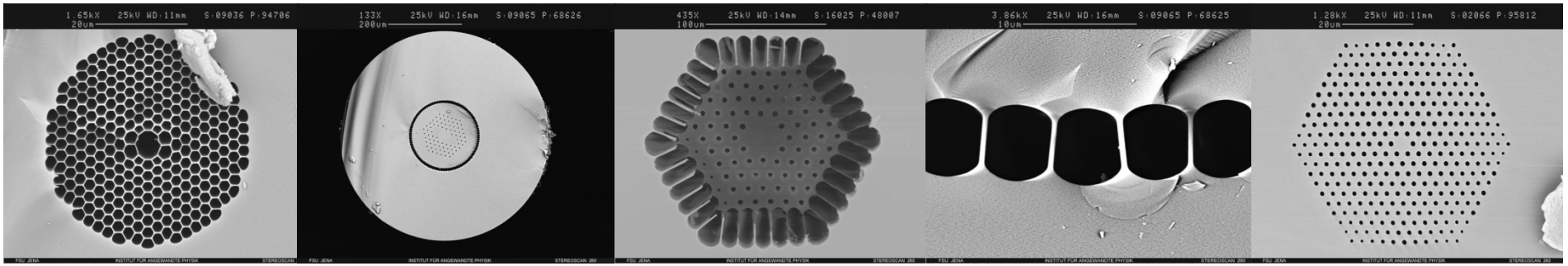
Scaling of fiber laser systems

Novel components and laser systems

- components:
  - novel fiber designs



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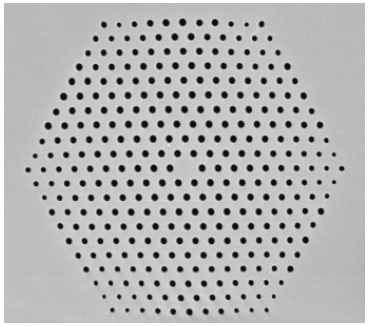
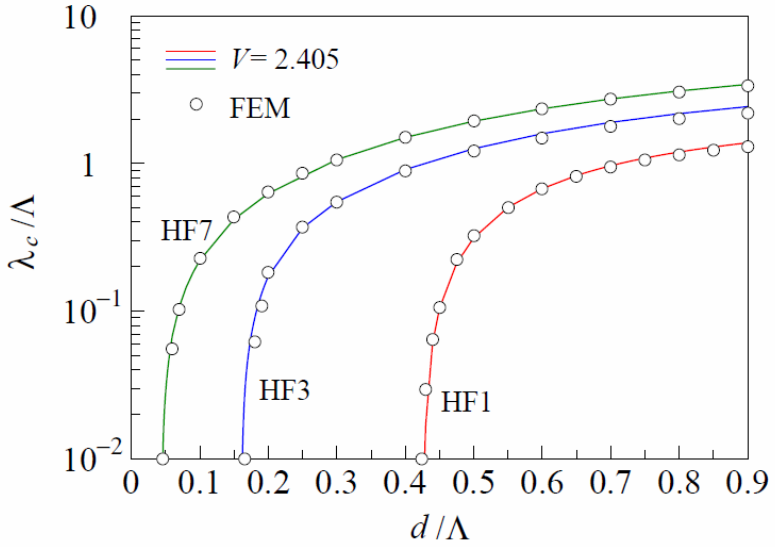
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties

endlessly single mode





Kunimasa Saitoh, Yukihiro Tsuchida, Masanori Koshiba, and Niels Asger Mortensen, "Endlessly single-mode holey fibers: the influence of core design," Opt. Express **13**, 10833-10839 (2005)

- MFD independent of λ
- SM from 0.5 to 2.5 µm

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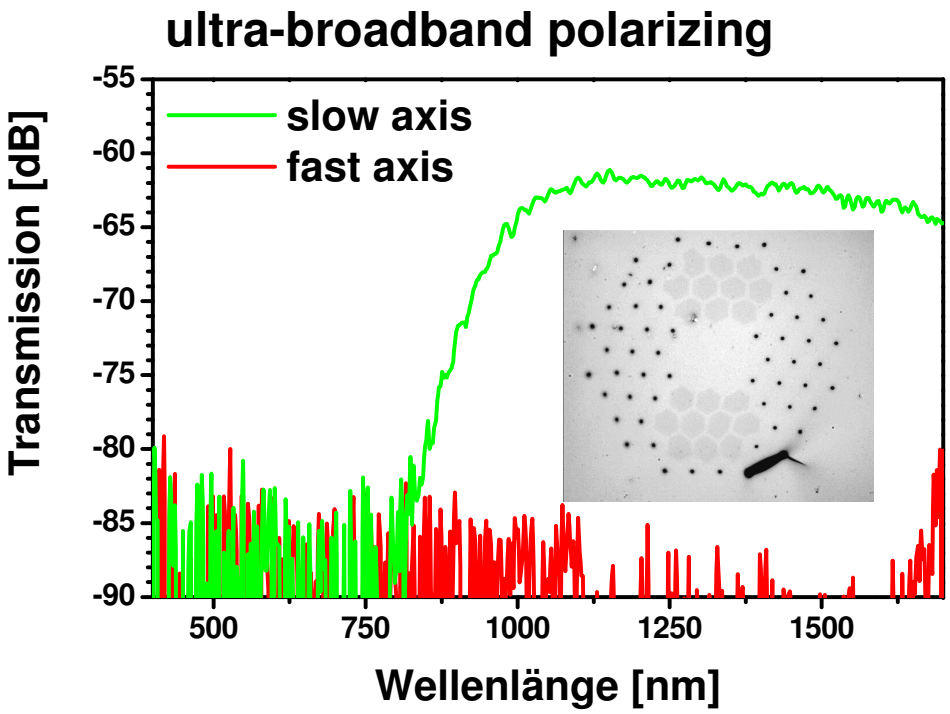
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties



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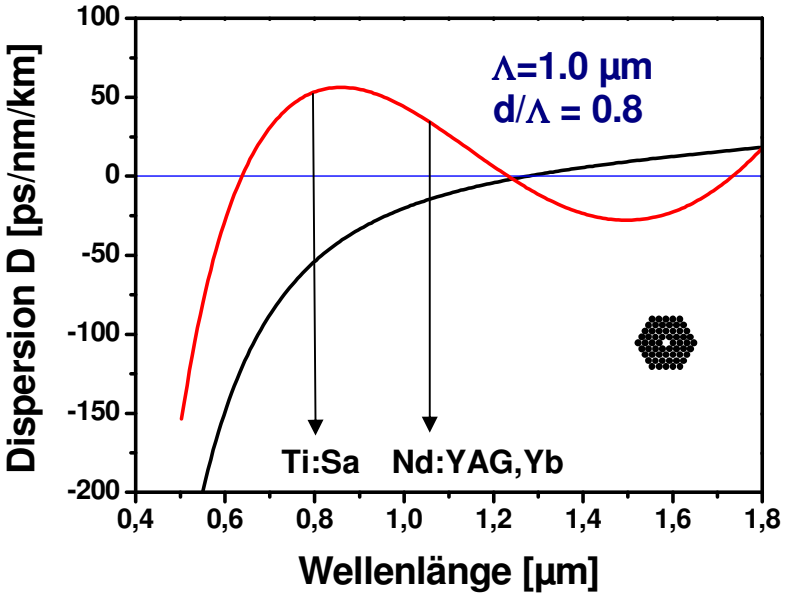
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties

extremly large dispersion shifts



enhanced nonlinearity A_{eff}~1..2 µm²

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Scaling of fiber laser systems
Novel components and laser systems

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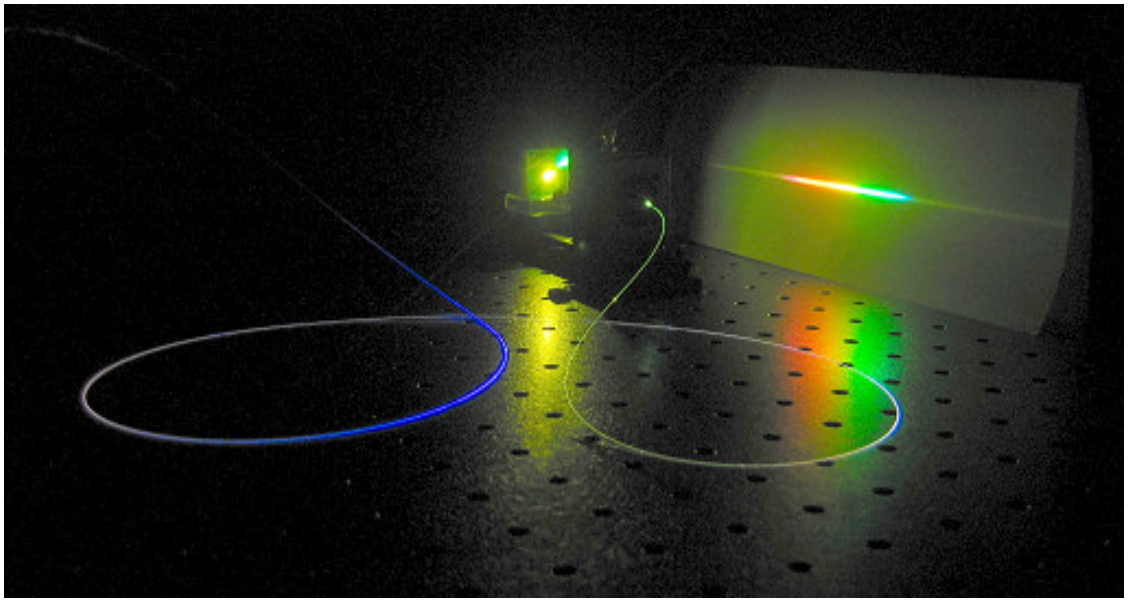

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Scaling of fiber laser systems
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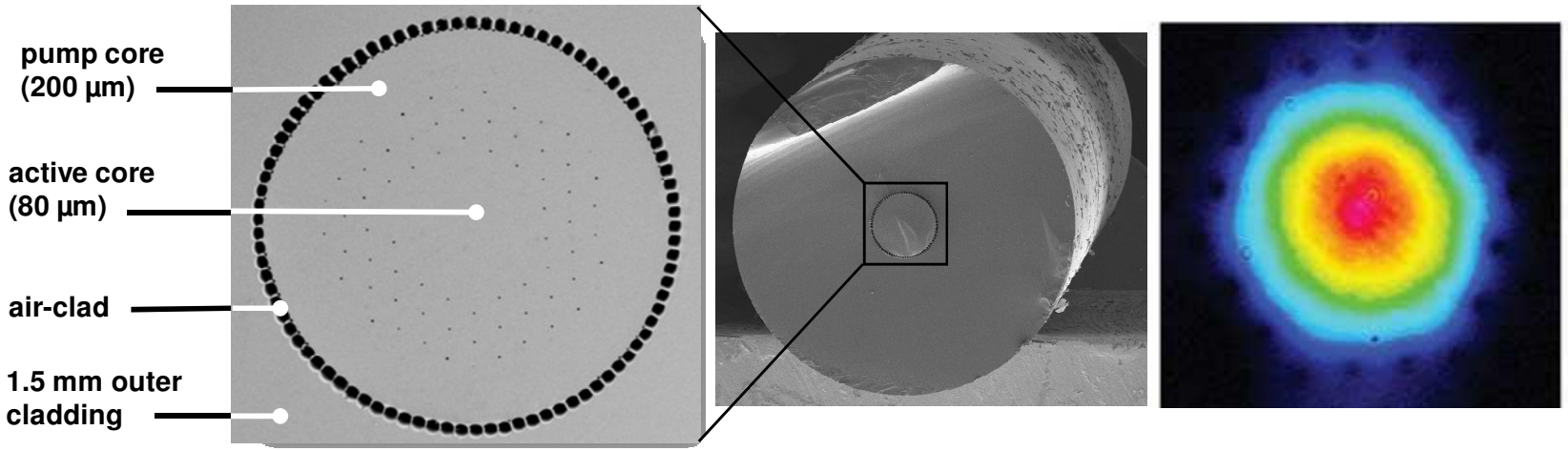
extremly low nonlinear interaction



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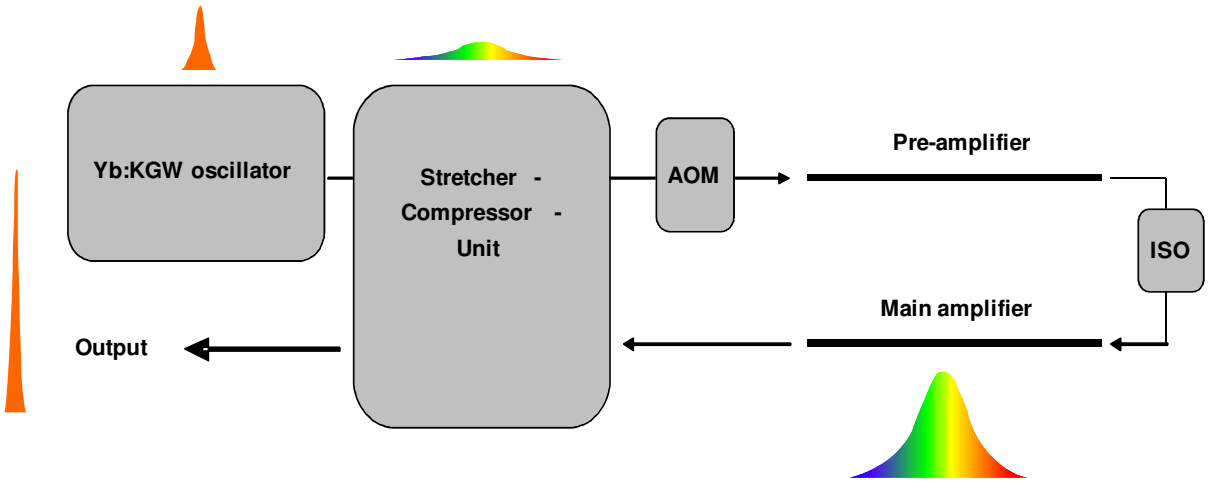

  - First GW fiber femtosecond system
  - First kW average power fiber femtosecond system

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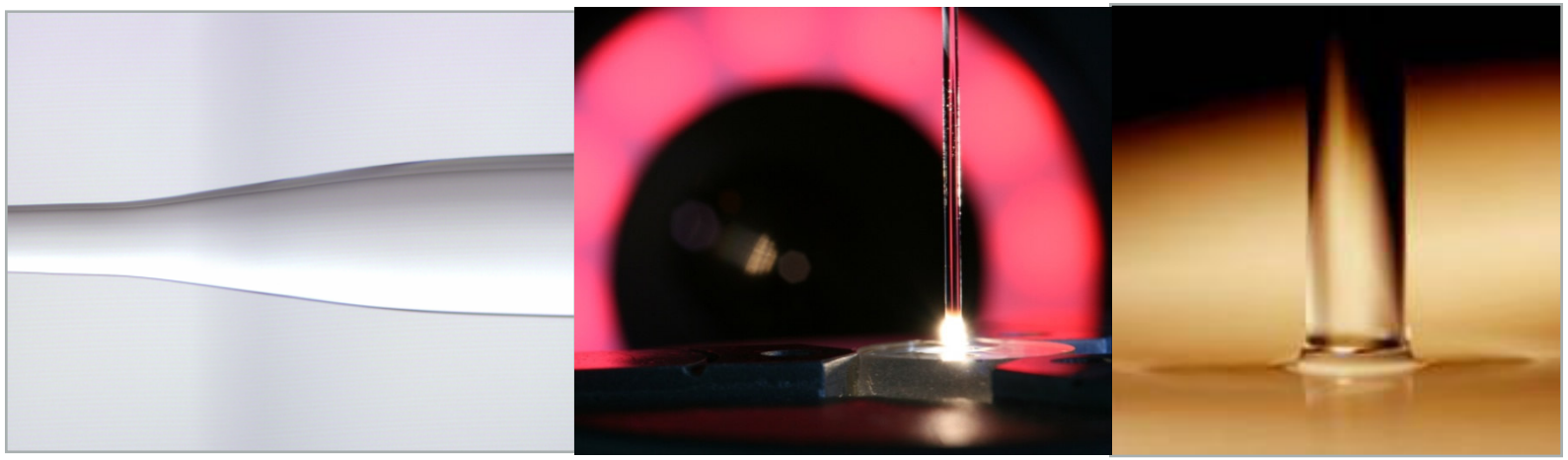
Scaling of fiber laser systems

Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties
  - fiber compatible components

tapers and endcaps



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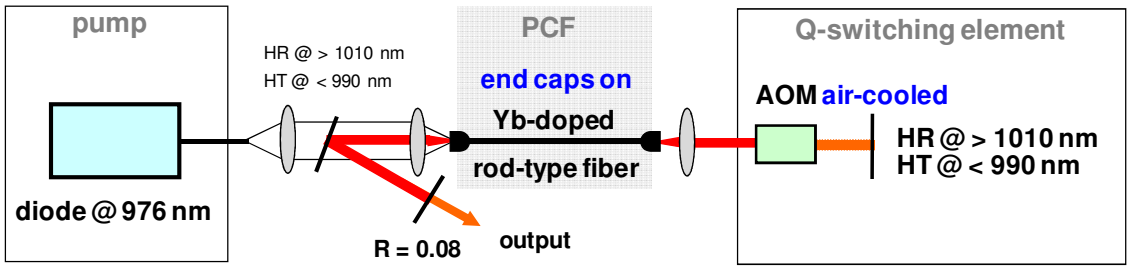

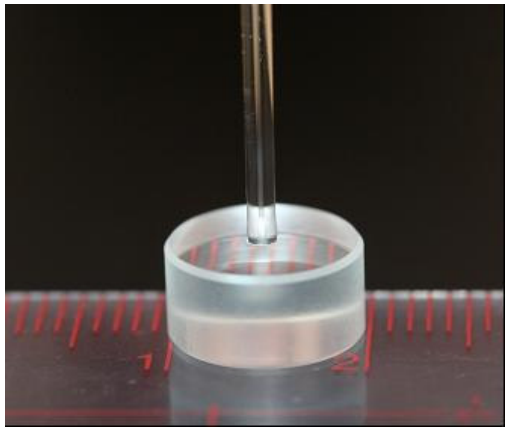

  - mJ, ns fiber laser systems

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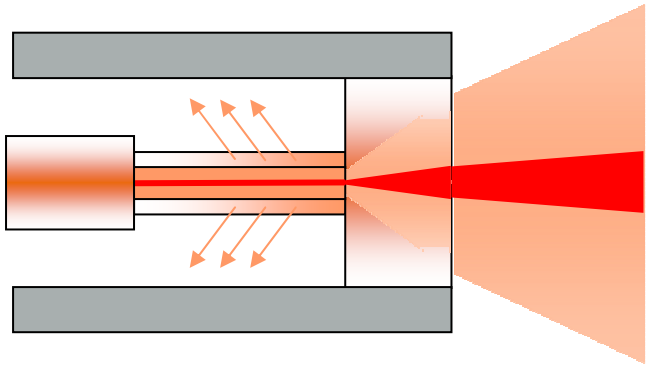
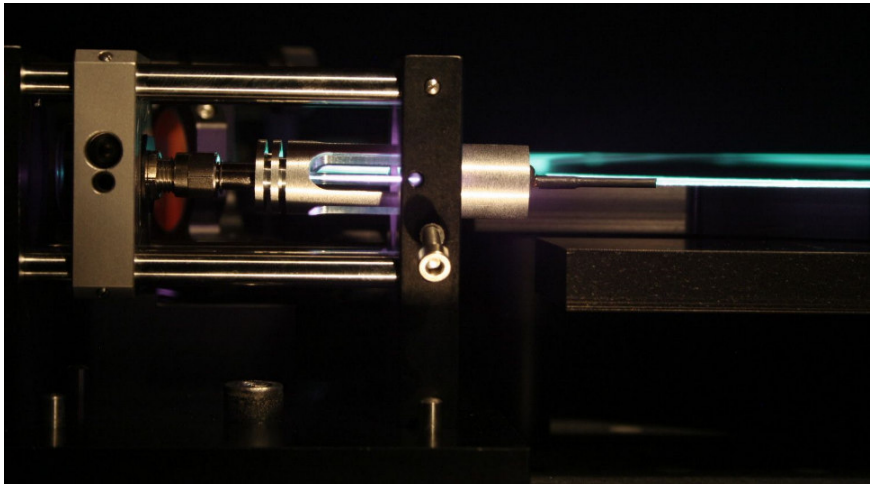
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties
  - fiber compatible components

mode-stripper and high power connector





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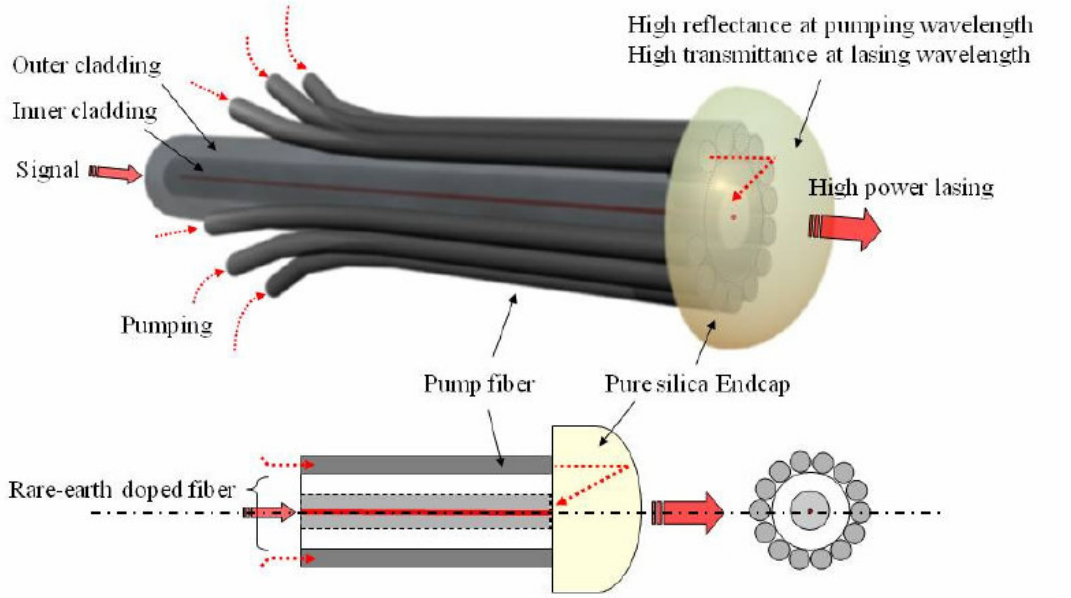
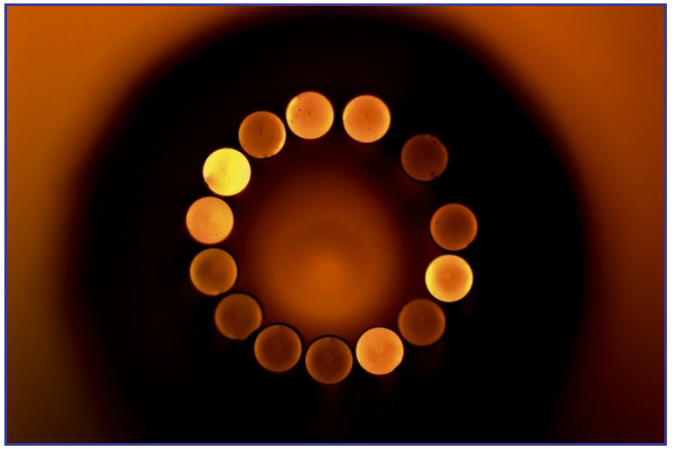
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties
  - fiber compatible components

Novel pump couplers





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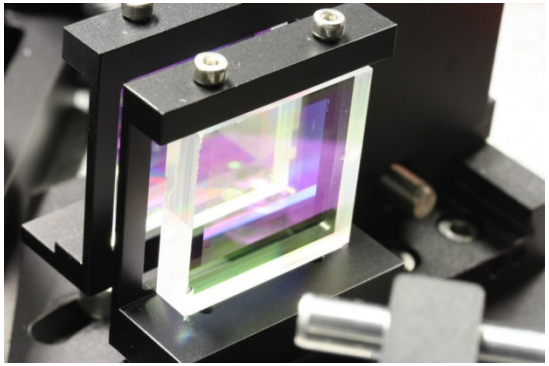
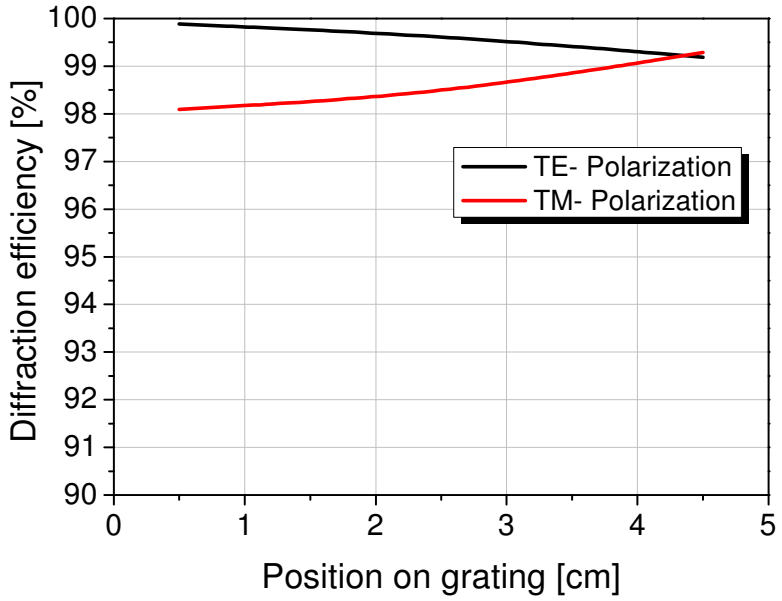
Scaling of fiber laser systems
Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties
  - fiber compatible components
  - High power components





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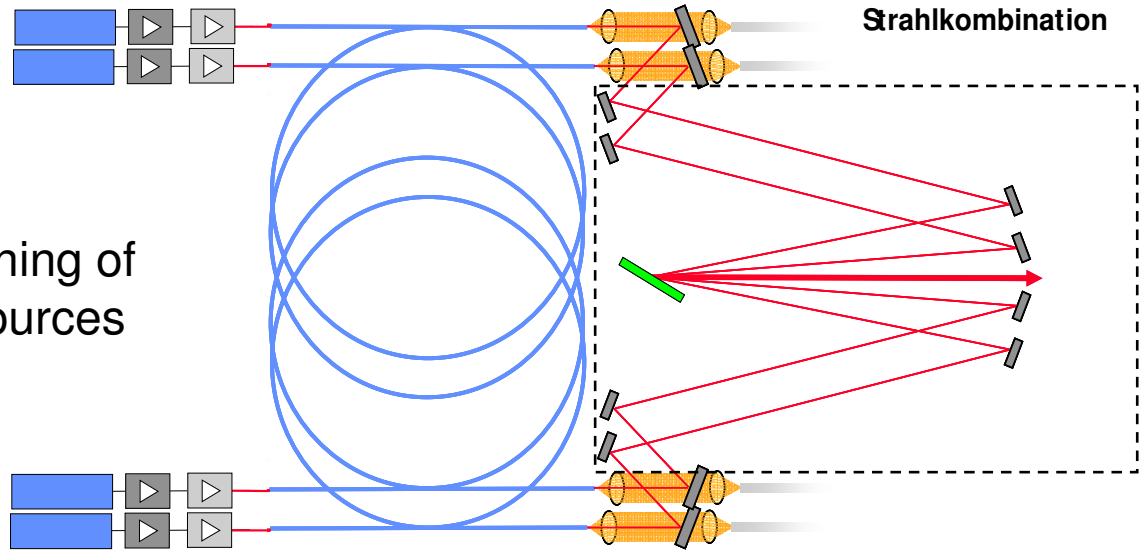
  - novel fiber designs = novel optical properties
  - fiber compatible components
  - High power components

spectral beam combining of **narrow linewidth** sources



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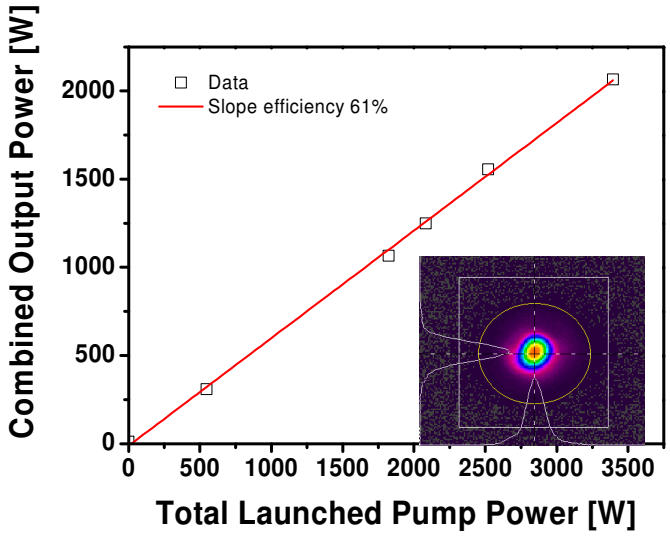
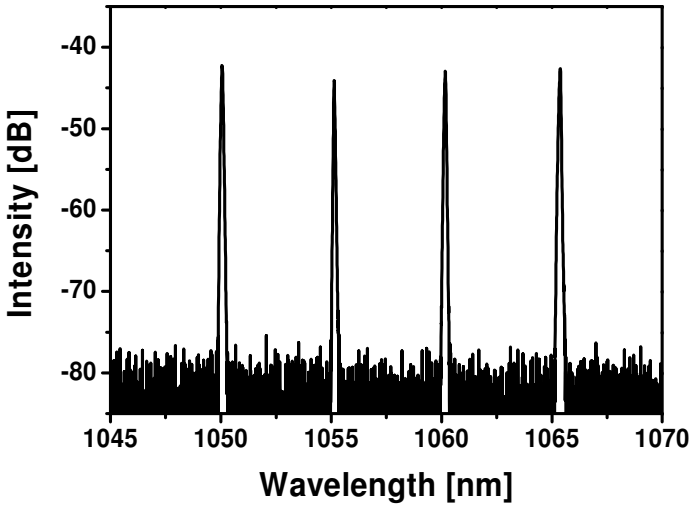
Scaling of fiber laser systems

Novel components and laser systems

- components:
  - novel fiber designs = novel optical properties
  - fiber compatible components
  - High power components





C. Wirth, O. Schmidt, I. Tsybin, T. Schreiber, T. Peschel, F. Brückner, T. Clausnitzer, J. Limpert, R. Eberhardt, A. Tünnermann, M. Gowin, E. ten Have, K. Ludewigt, and M. Jung, "2 kW incoherent beam combining of four narrow-linewidth photonic crystal fiber amplifiers," Opt. Express 17, 1178-1183 (2009)

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Outline

- introduction
- packaging and joining technologies
  - Application to microchip lasers
- novel components
  - Applications to fiber laser system scaling
- **example of MID-IR source**
- possible further directions
- summary

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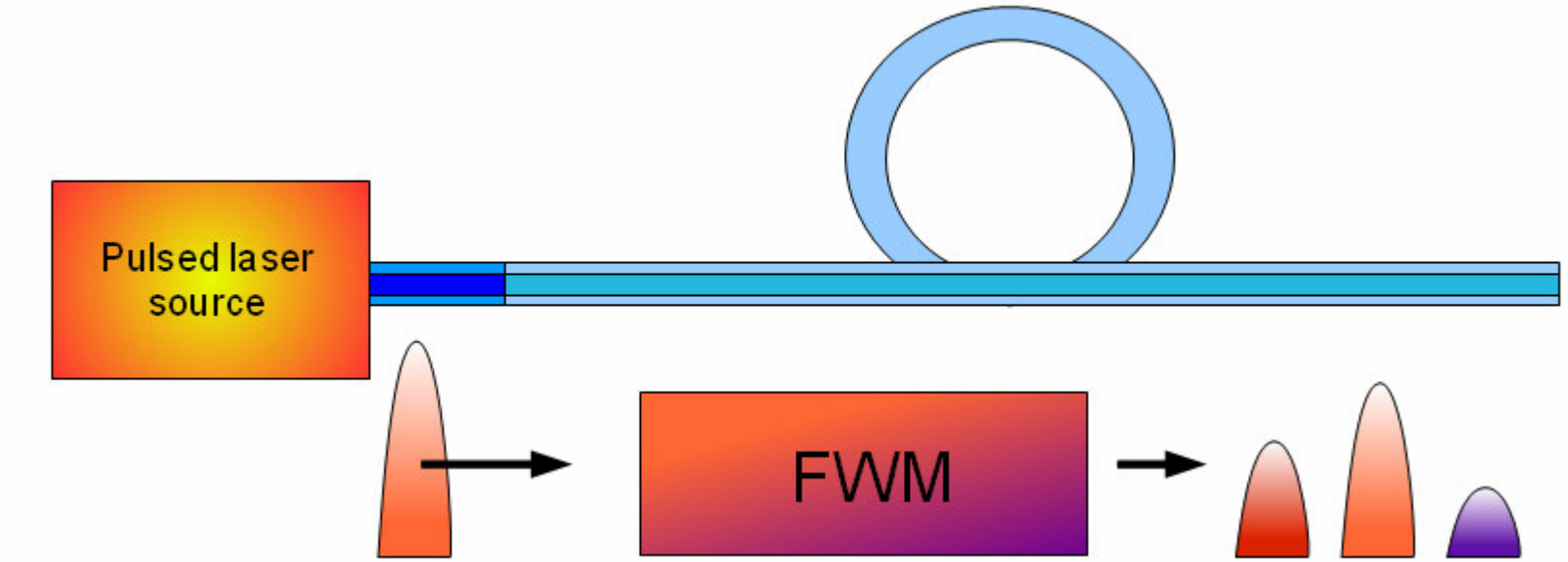
Scaling of fiber laser systems
Novel components and laser systems

- Approach for a fiber based picosecond VIS and MIR source



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Degenerated FWM

a)	$2\omega_1 = \omega_2+\omega_3$	Energy conservation
b)	$2k_{pump}=k_{signal}+k_{idler}+\gamma P_1 = 0$	momentum conservation
c)	Low losses at ω_1, ω_2 and ω_3	No attenuation of the waves
d)	$MFD_{Signal} \approx MFD_{Pump} \approx MFD_{Idler}$	Good overlap of the involved waves

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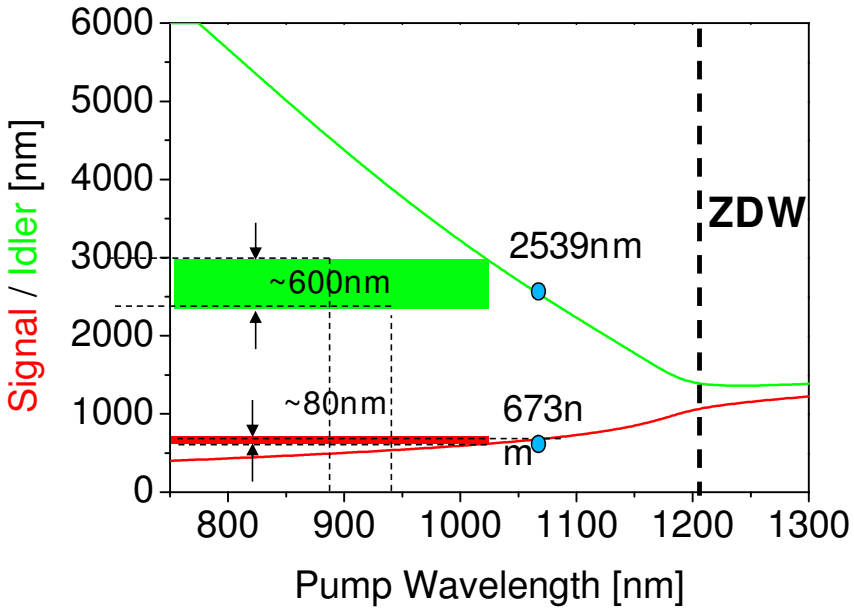
Condition a) $2\omega_1 = \omega_2+\omega_3$ + b) $2k_{pump}=k_{signal}+k_{idler}+\gamma P_1 = 0$

Nonlinear phase-matching diagram
(Pump power = 40kWatt)



To get widely separated signals move the pump wavelength far away from the ZDW (in the normal dispersion regime)

Furthermore, the amplification bandwidth is given by:

$$\Omega_A \approx \frac{\gamma P_o}{|\beta_2|\Omega_s}$$

Thus, additionally **to get narrowband signals** we need:

- high dispersion
- high separation of the wavelengths

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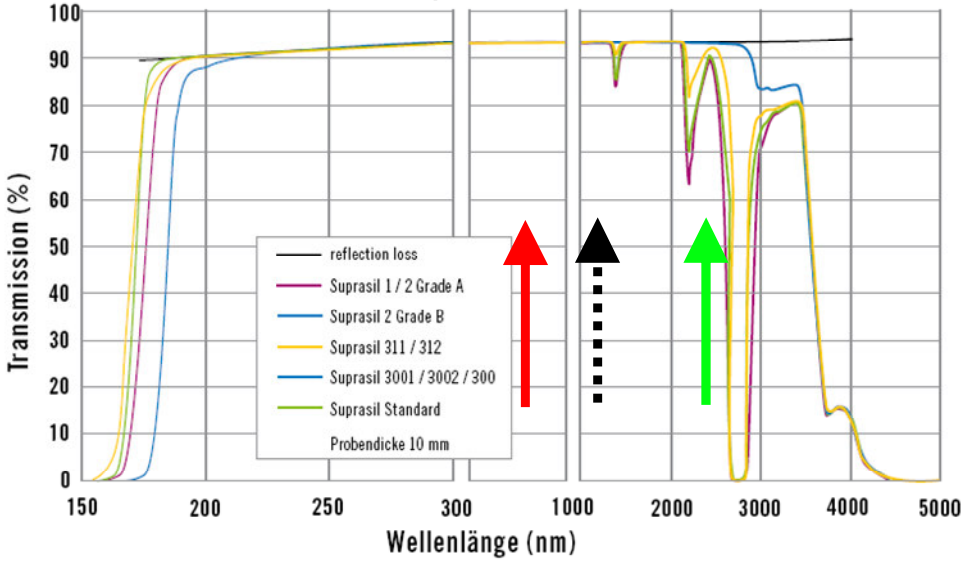
Condition c) Low losses at ω_2 and ω_3

Analyze the phase-matching condition a) and b) and look for a material which transmission window fullfils c)

Transmission spectrum of fused silica



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IR graded fused silica is a good candidate to use with tunable lasers from 1020-1090nm!

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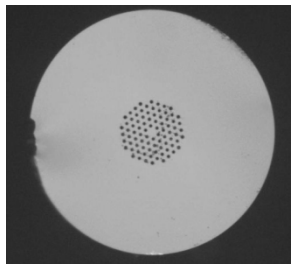
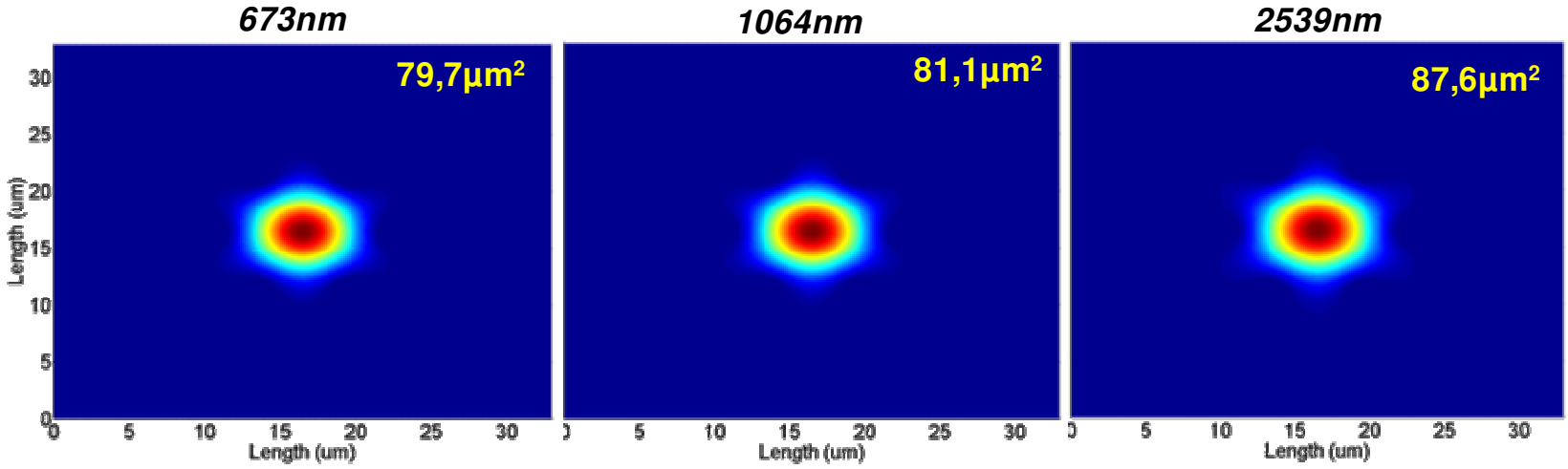
Condition d) $MFD_s \approx MFD_p \approx MFD_i$



Use an **endlessly single mode design** to ensure good mode field overlap for all involved wavelengths. E.g. an LMA-10 PCF.

Mode field distribution in LMA-10 fiber for signal, pump and idler waves:



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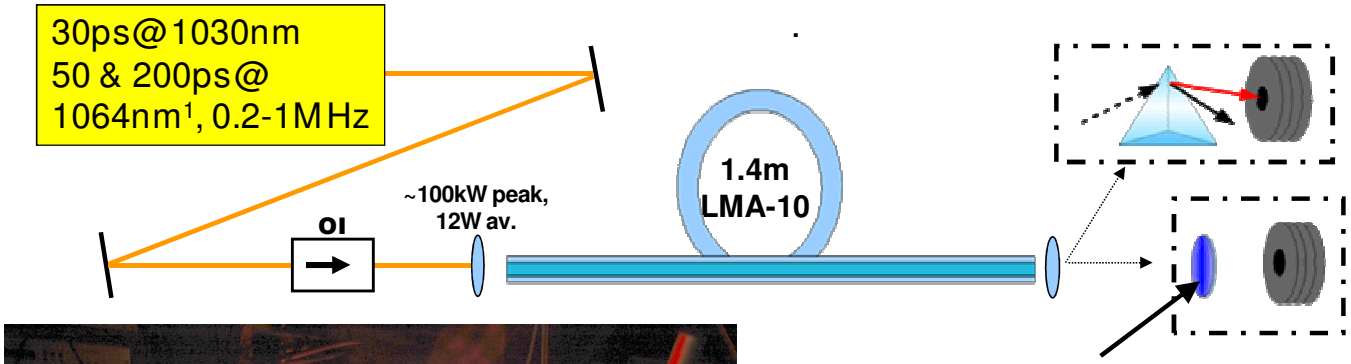

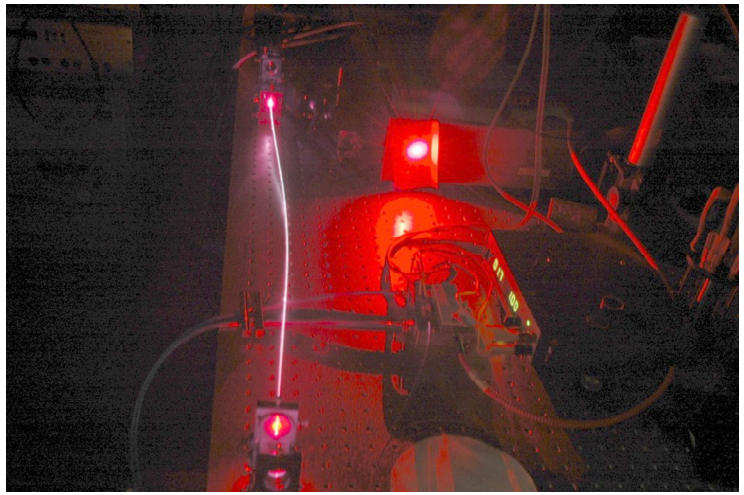

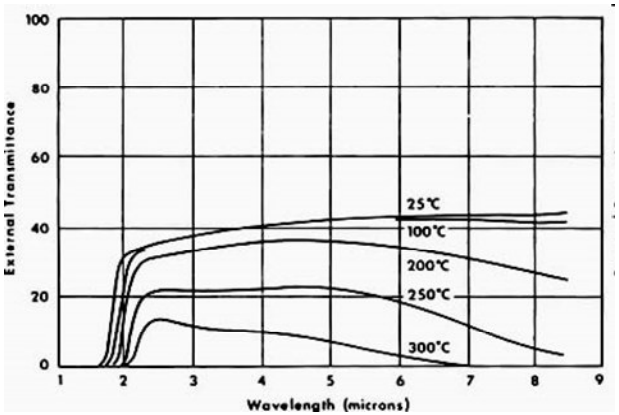

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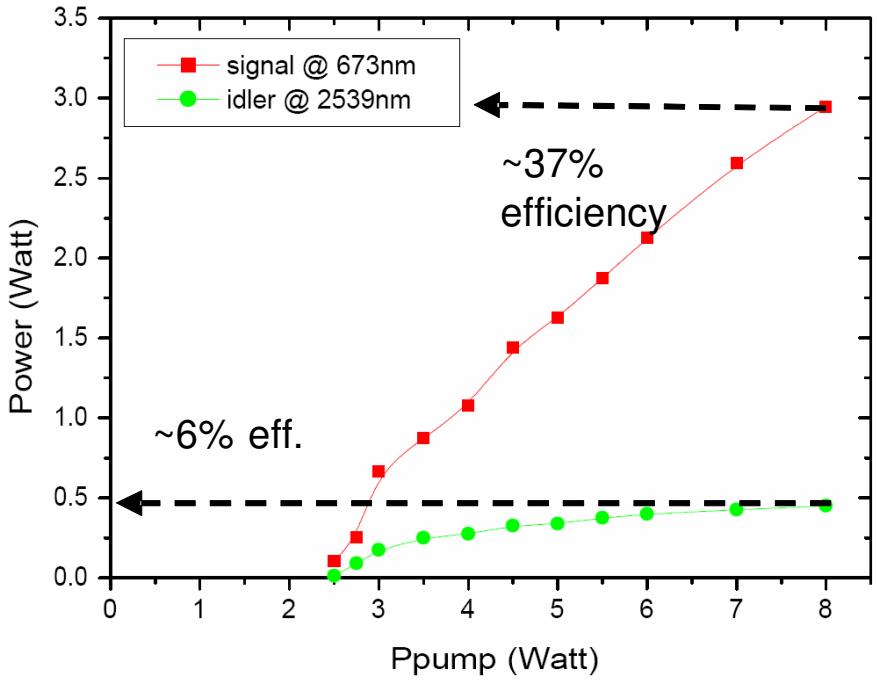
Scaling of fiber laser systems
Novel components and laser systems

- Approach for a fiber based picosecond VIS and MIR source

Slopes of the signal and idler wave average power with 200ps pulses and 1MHz rep. rate.

Av. power slopes of signal and idler



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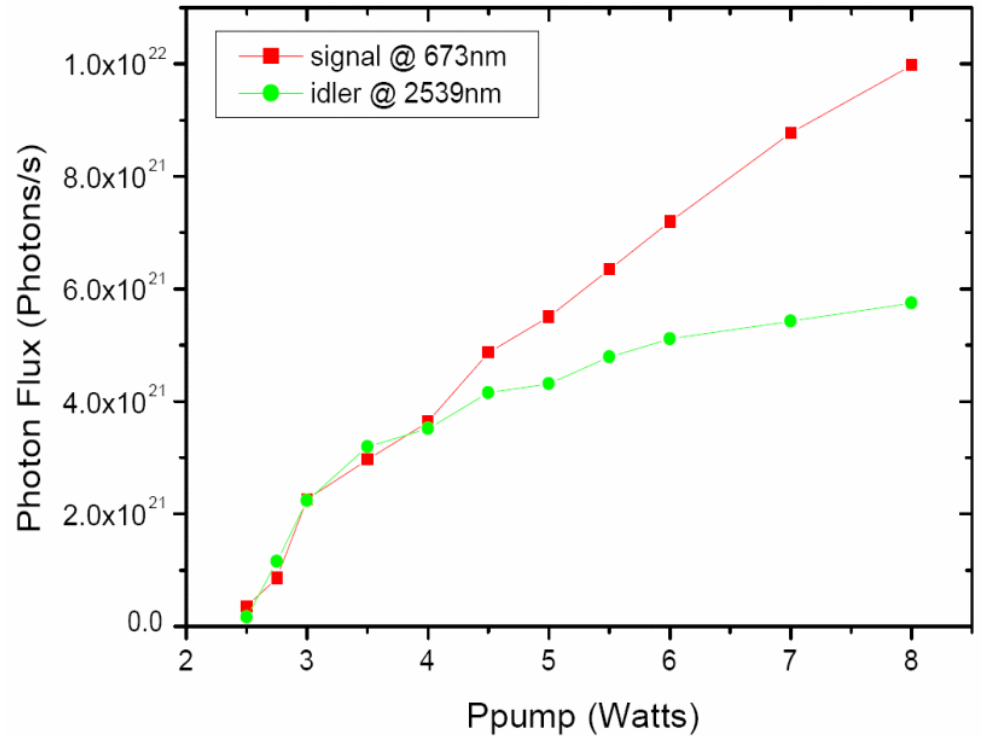

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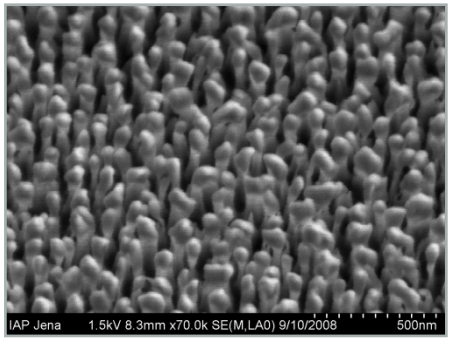
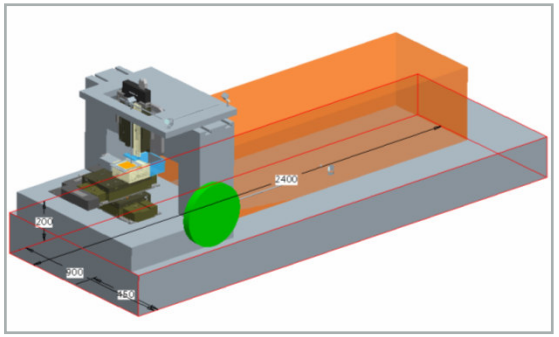
Packaging and Joining Technologies for fiber lasers – further directions

- using other NLO-elements + high power silica fiber lasers
  - e.g. quasi phase-matching (orientation-patterned GaAs)
  - transparent (low absorption), nonlinear materials + bonding process (for thermal contact)
- anti-reflection properties on MID-IR fibers
  - effective media directly bonded to fiber end facet
- fiber bragg gratings
  - written by femtosecond pulses

    (for non UV-sensitive fibers)

  …





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SET-171 Mid-IR Fiber Laser Workshop

Scaling of fiber laser systems based on novel components and high power capable packaging and joining technologies